Sensors & Transducers, Vol. 178, Issue 9, September 2014, pp. 286-291

Sensors & Transducers

http://www.sensorsportal.com

Design and Realization of Intelligent Flow Controller

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Received: 15 April 2014 /Accepted: 29 August 2014 /Published: 30 September 2014

Abstract: According to accurate flow rate control requirements in large irrigation zone, a fuzzy controller with dead-band is designed on the characteristics analysis and comparison of PID and Fuzzy. The setting values of water flow for gates are determined by real-time water level detection sensors, and the realistic value of discharged water and gate opening are detected out with relative sensors, simulation manifest that the specific control strategy can adjust the gate swiftly in circumstance of huge offset, and regulate the gate slightly in time of small bias, it is realized with Siemens S315 PLC (Programmable Logical Controller) and has being working steadily for 2 years, the aim of regulation is performed properly. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: *PLC, Fuzzy, PID, Flow Rate, Strategy.*

1. Introduction

A network sluice gate control system is designed for large scale irrigation system, it aims to regulate the water amount adjusting gate opening. The system is divided into three layers from its construction, named local system, sub information center and main info center, all of the parts are connected together with industry internet. the local system includes PLC, sensors, pumps and gates, etc.; the sub information center consists monitoring computers, served as working station and engineering station, configure software WinCC runs and supervises relative PLCs, the signals are transmitted to PC in sub center with fiber or twist wires; main information center communicates with sub centers by means of VPN (Virtual Private Network) on the base of public internet, system structure is shown as Fig. 1.

Various detection sensors, such as water level sensors, gate opening sensors, water flow sensors, motor temperature sensors and current sensors, carry out the measuring tasks and then send out signals to PLC, for controlling the gate to regulate the water drainage. Different control strategy leads to different working efforts, particularly in control speed and accuracy [1-3].

Two different flow rate control algorithm are discussed and the performance are compared by simulation and practical running, the realization method is given out later for the better one. This project can not only adjust the flow exactly, but can also manage the branches of large scale irrigation with networks, so that it can let us use the water more efficiently.

2. Page Controller Design for Flow Rate

Different controller leads to different outputs even at the same conditions, PID and Fuzzy strategy are discussed here. For both of controllers, the wanted flow rate is determined by current water level which is to be called as setting value. The real-time water flow is measured by sensors which are located behind gates, by analysis the bias and it's changing between the setting flow and real flow, both controllers then give out the desired outputs for each gate.

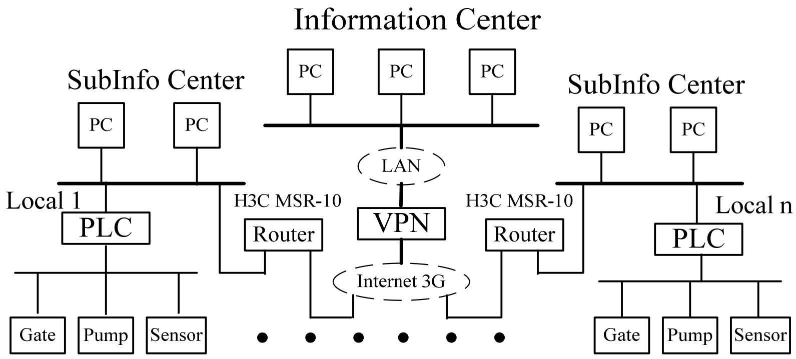

Fig. 1. Structure of gate control system.

2.1. Design of PID Strategy

PID controller is very popular, especially used in the circumstance of linear and time-invariant system [4-7], when object model is established, the controller works well by setting proper parameters of P, I, and D. its structure is given out as below.

In Fig. 2, $e(k) = r(k) - y(k)$, $\Delta e(k) = e(k) - e(k-1)$, where K means each moment of sampling, and then, the u(k) can be gotten as PID algorithm.

$$u(k) = K_P \left\{ e(k) + \frac{T}{T_I}\sum_{j=0}^{k} e(j) + \frac{T_D}{T}\left[e(k) - e(k-1)\right] \right\}$$
$$= K_P e(k) + K_I \sum_{j=0}^{k} e(j) + K_D \Delta e(k)$$

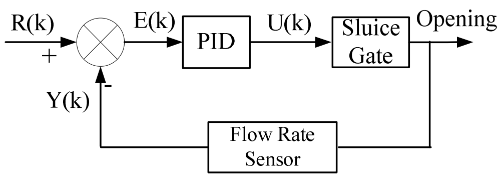

Fig. 2. Structure of Gate Control System with PID

At last, because the gate moves from its previous position, so the increase PID is adopted.

$$\Delta u(k) = u(k) - u(k-1) =$$
$$= K_P\left[e(k) - e(k-1)\right] + K_I e(k) +$$
$$+ K_D\left[e(k) - 2e(k-1) + e(k-2)\right] =$$
$$= K_P \Delta e(k) + K_I e(k) + K_D\left[\Delta e(k) - \Delta e(k-1)\right]$$

For PID works on the base of $e(k)$, and the system is obvious a time-variant one, it is interfered by many factors, such as wind, waterfall, results can't meet the requirements.

2.2. Design of Fuzzy Strategy

Fuzzy controller is a kind of intelligent manipulator, it works on the experts' experience and needn't acquiring the objects' exact model, so it is now widely used in project [8-12]. it includes three parts, named as Fuzzy, De-Fuzzy and determine Rules, in which the rules are kernel of controller, they are very important and should be complete and cover all probability, additionally, each rule should be coherent with others. The control structure is shown as Fig. 3.

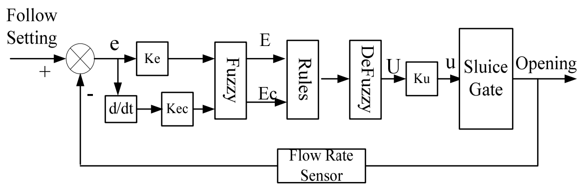

Fig. 3. Structure of Gate Control System with Fuzzy.

2.2.1. Fuzzy Operation

Flow rate bias and its change are expressed as *e* and *ec*, they serve as input variables and mainly changes from -150 to 150, they are transformed to E, EC with quantitative factors K_e, K_{ec} separately. The values of *E*, *EC* are limited in Fuzzy domain [-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6] which is divided by subset [NB, NM, NS, ZO, PS, PM, PB], the Fuzzy domain of variable *U* is also [-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6], it should be changed to relative gate opening from -100 to 100 by scale factor Ku. Quantitative factor and scale factor have perceptible impact on controller performance, they should be determined according to the following formula and refined by practical running.

$$E = \begin{cases} 6 & E > 6 \\ \left[Ke * e\right] & -6 \le E \le 6 \\ -6 & E < -6 \end{cases},$$

where [ ] means rounding operation

By using of Triangle-shape grade membership function, *E, EC* and *U* can all be expressed with linguistic variable in Fuzzy subset, which is shown in Fig. 4.

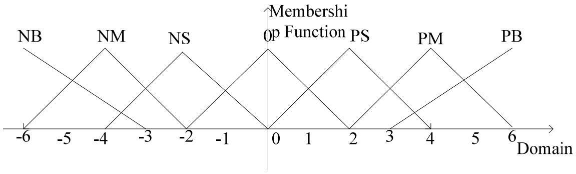

Fig. 4. Membership grade curve of variable.

2.2.2. Control rule

Control laws come from experience, as we know, the output should be large while E is big, the steering rapidity is the most important and EC can be ignored to some extent; when E is small enough, the stability becomes more vital, the main target should be to eliminate E, and EC can't be ignored now, all of these rules constitute a integrated rule set.

In addition, to keep system stable while E is very small, a dead-band is added into the rule set, which is listed in Table 1.

Table 1. Fuzzy control rules.

U		*EC*						
		NB	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*
E	*NB*	*NB*	*NM*	*NM*	*NB*	*NM*	*NS*	*NS*
	NM	*NS*	*NS*	*NM*	*NB*	*NS*	*NS*	*ZO*
	NS	*ZO*	*NS*	*NS*	*NS*	*ZO*	*ZO*	*ZO*
	ZO	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*
	PS	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*	*ZO*
	PM	*PM*	*PS*	*PS*	*PS*	*PS*	*PS*	*PB*
	PB	*PB*	*PM*	*PS*	*PS*	*PS*	*PM*	*PB*

2.2.3. Output of Controller

The rule set describes the output according to experience in a described ways, how to get out the proper output values from these linguistic laws is the aim of defuzzy. There are three major methods and the centre-of-gravity method is widely used, it is adopted here to calculate the value of U(k). The primary progress is as follows.

Fuzzy rule: if $E=A_i$ and $EC=B_j$ then $U=C_{ij}$ (i=1…m, j=1…n)

Fuzzy relation R: $R = \bigcup_{ij} A_i \times B_j \times C_{ij}$

Member Function of R:

$$\mu_R(a,b,c) = \bigvee_{i=1,\,j=1}^{i=m,\,j=n} \mu_{Ai}(a) \wedge \mu_{Bj}(b) \wedge \mu_{Cij}(c)$$

where $\vee$ means max operation;

$\wedge$ means min operation.

For the input of e^*, ec^*, output is: $U=(e^* \times ec^*) \circ R$

Member Function of U:

$$\mu_U(c) = \bigvee_{a \in A, b \in B} \mu_A(e^*) \wedge \mu_B(ec^*) \wedge \mu_R(a,b,c)$$

Centre-of-gravity algorithm for U:

$$U^* = \frac{\sum \mu(U_i) \cdot U_i}{\sum \mu(U_i)}$$

An approximate output can be given out after the steps above, and then amended by necessary modification (Table 2).

Table 2. Fuzzy Control Output.

U		EC												
		-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
E	-6	5.96	5.83	5.95	5.9	5.9	5.8	5.8	4.77	4.0	3.20	2.30	2.20	2.0
	-5	5.87	5.82	5.87	4.77	4.60	4.50	4.50	3.53	2.80	2.80	2.60	1.18	0.80
	-4	4.60	4.50	4.40	4.20	4.10	4.10	4.0	3.0	2.0	1.95	1.80	1.18	0
	-3	4.10	3.96	3.77	3.7	3.3	3.3	3.0	3.0	2.0	1.90	1.60	1.18	0
	-2	3.20	2.92	2.60	2.45	2.28	2.20	2.10	2.05	2.0	1.80	1.50	1.18	0
	-1	2.30	1.63	1.40	1.30	1.30	1.25	1	0	0	0	0	-0.8	-2.0
	0	0.30	0.30	0.25	0.20	0.15	0.10	0	-0.1	-0.15	-0.20	-0.25	-0.25	-0.30
	1	2	1.70	1	0	0	0	-0.8	-0.9	-0.9	-0.9	-1.0	-1.0	-1.2
	2	0	0	0	-0.1	-0.6	-0.8	-1	-1.2	-1.2	-1.4	-1.4	-1.6	-1.6
	3	0	-1.10	-1.10	-1.10	-1.21	-1.32	-1.81	-2.01	-2.20	-2.32	-2.50	-2.50	-2.54
	4	0	-1.18	-1.47	-2.0	-2.11	-2.32	-2.54	-2.61	-2.70	-2.82	-2.94	-3.0	-3.2
	5	-0.82	-2.02	-2.72	-2.80	-2.81	-3.10	-3.2	-3.25	-3.32	-3.57	-3.72	-3.81	-4.01
	6	-2.04	-3.18	-4.0	-4.0	-4.10	-4.12	-4.20	-4.28	-4.44	-4.62	-4.87	-5.01	-5.15

The behavior characteristics of different controllers can be simulated by Matlab, the ability of tracing a step signal or anti the short time interference is often used to evaluate controller, the result in Fig. 5 indicates that Fuzzy controller can adjust the flow rate meticulously, it works more fluently and its overshoot is obviously less than PID.

3. Realization of Fuzzy Controller with PLC

3.1. Design of Hardware

In view of hardware, the control system includes computers, PLCs and communication devices, the computers are located in information center and monitor all equipments, the PLCs play an important role and realize the manipulate strategy, the communication devices mainly work on industry internet work, they transmit information between terminals with TCP/IP protocols.

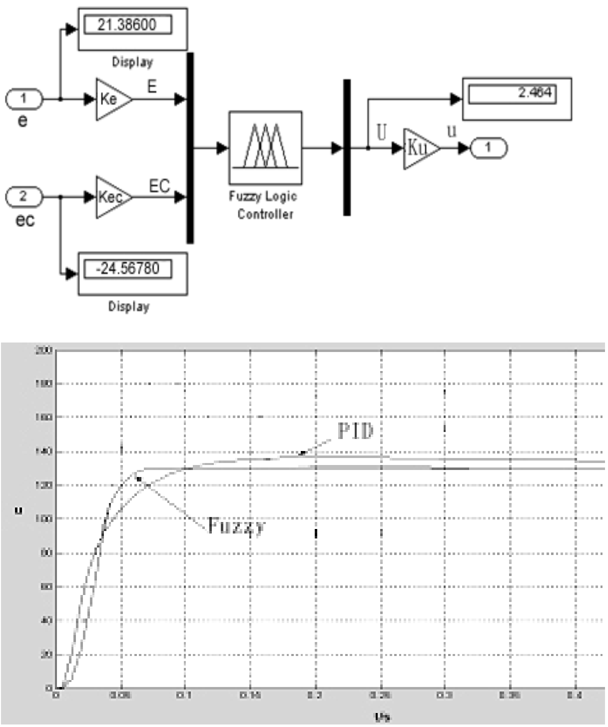

Fig. 5. Comparison of Fuzzy and PID.

As to the selection of PLC, for the industry internet is adopted, so Siemens S315-2DP is picked out for it has 2 high-speed DP connectors, and can be accessed to internet with extended net module. In addition, the expand modules 331-7KF02 are also used to access all kinds of sensors, and convert the initial analog value to digital data. The sensors include throw-in water level sensor TY-100, ultrasonic flow rate meter TH-990M, and draw-wire displacement sensor SMW-LX for gate opening.

3.2. Design of Control Software

The PLC works in Cycling Scanning method, and rules listed in Table 2 are stored in flash memory of S315 already, the water flow rate bias e and ec are changed to E, EC, the U can be deduced out, then u can be calculated by multiply Ku.

As an integrated development environment, SIMATIC V5.4 provide two kinds of different program modules, they are FC and FB, which can be called by OB block or other blocks, both FC and FB need parameters to be run, real parameters are applicable for FC, and instance data DB for FB, with the changing of parameters, the same FB(FC) block can be used in circumstance of “the same progress, the different object”, the flow chart of fuzzy control and treat of rules are shown in Fig. 6 (a and b) respectively.

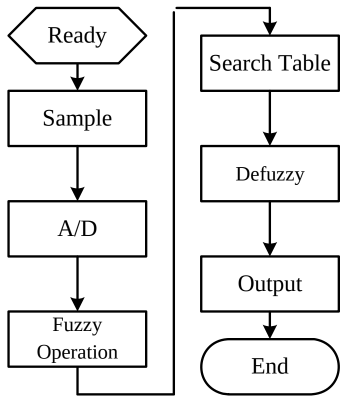

Fig. 6 (a). Flow chart of control.

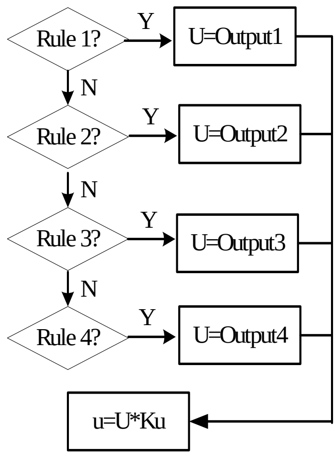

Fig. 6 (b). Flow chart of rules.

Comparison function is used to realize the Fuzzy rules (Fig. 7), according the flow rate E, EC, the best value of R is selected out.

In the parameter 5, rule 66 is used to select out the value of 1#U66 for gate 1; and the rule 65 is used for determining whether the 1#65 should be put into use.

One FC block is used for one gate, while all the FC blocks are called by OB1, the control for all gates can be fulfilled.

3.3. On-line Communication Detection

This function is designed for unexpected interrupt between Information Center and local PLC. It is dangerous if the communication break down while the PLCs are driving the gates, and in the mean time, operators don’t know anything about local site and no proper measures are taken by PLCs automatically. So the aim of detection function is to find out the failure and stop the devices in time, and sent out relative signals.

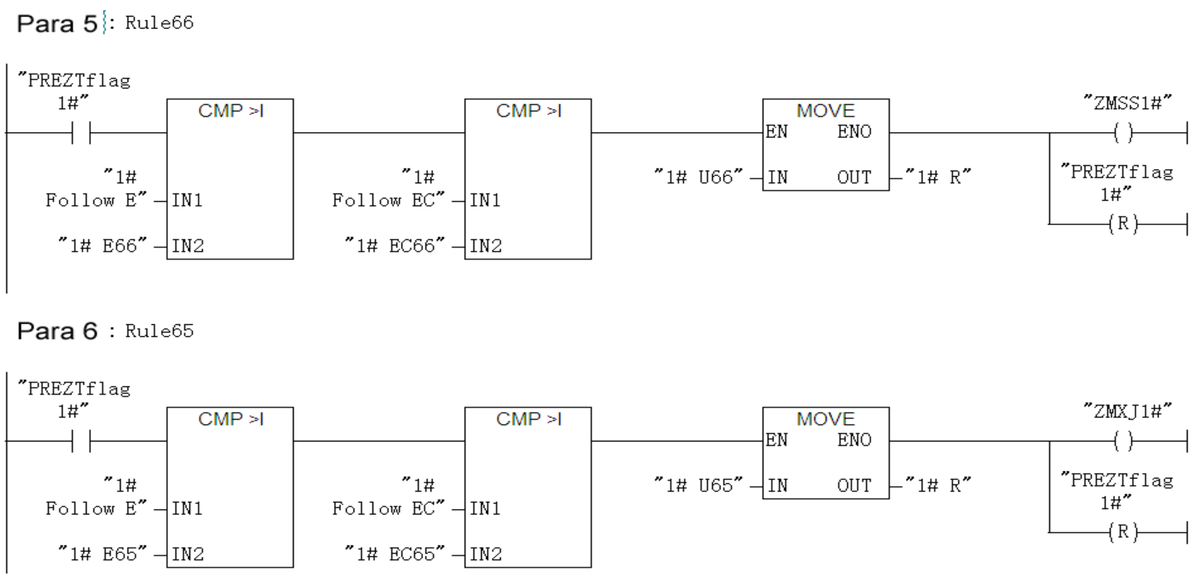

Fig. 7. Realization of fuzzy rules.

The working principles can be described as follows, a special variable is set in monitoring computer, and it is trigger by a 20 ms timer, it plus 1 at each interrupt which is programmed with VB script, so it can be repeatedly within 0~100 continuously. This variable is sent to each PLC while the communication works well. In the same time, a queue table is built in PLC with this variable, the new data input into the end of table, and comparison operation is carried all the time, the data should be unequal in normal, so if equal number occurs for more than 3 times, it means the data may not be refreshed and conclusion can be drawn out that the communication is wrong. In this case, PLC will stop gates immediately.

4. Conclusion

According the nonlinear character of water flow control in large irrigation zone, a Fuzzy controller with dead-band is designed and realized. Its setting value is given out by present water level, the PLC gives out e and ec of water flow at each sampling time, and then sent out u according to relative rules. Practical operation shows that Fuzzy system is better than PID, it has the merits of slight overshoot, fast response and high accuracy in stability, especially with the help of dead-band, it can decrease the frequency of gate adjusting obviously.

Acknowledgments

The research is sponsored by China Postdoctoral Science Foundation (20080441085), Natural Science Foundation of Jiangxi Province, China (2010GZC0144), Technology Plan of Educational Commission, Jiangxi Province China (GJJ12627).

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